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(54) **Rare gaseous discharge lamp, lighting circuit, and lighting device**

(57) A rare gaseous discharge lamp arrangement that takes into account the electrostatic capacity of the lamp structure. It's discharge vessel has an outside diameter D mm, thickness t mm, and dielectric constant ε and satisfies the relation

$$0.01 < t / (D \cdot \varepsilon) < 0.05.$$

The lamp has at least a pair of electrodes, at least one of which is external.

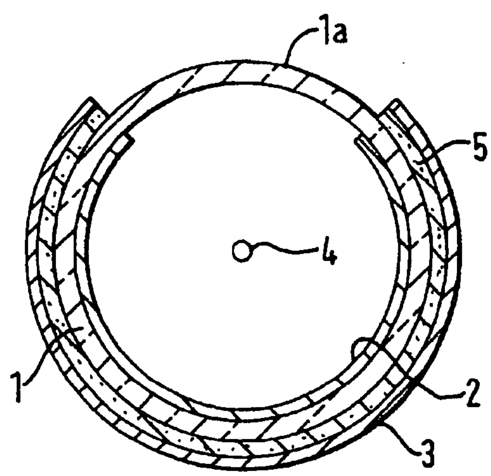

FIG. 1

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Description

INCORPORATION BY REFERENCE

[0001] This application incorporates the subject matter of Japanese Patent Applications 10-84737 filed 03/30/98; 10-182729 filed 06/29/98; 10-213955 filed 07/29/98; 10-216347 filed 07/31/98; 11-11031 filed 01/19/99; as if fully set forth herein.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates in general to fluorescent lamps and to methods of operating them. More particularly, the invention pertains to rare gas discharge lamps, their structural configurations and to methods of operating them.

Description of Related Art

[0003] Discharge lamps using mercury had become popular because of their operational characteristics. However, due to environmental concerns, there have been efforts to make discharge lamps without mercury. This has presented design challenges.. Now there are rare gas discharge lamps which use rare gases, such as the xenon, as a discharge medium enclosed within a transparent discharge vessel. Such lamps can be made to have a reasonable luminous flux stand up characteristic at low temperature. However, rare gas discharge lamps having only internal electrodes generally do not have sufficient luminescence for many uses.

[0004] Rare gas discharge lamps can be made with one or more external electrodes. By using at least one electrode positioned along the longer side of the external surface of the transparent discharge vessel, the amount of luminescence can be increased. Such lamp arrangements are particularly suitable for reading. However, external electrode lamps have various structural and operational problems. They must be operated at a high voltage, typically 5 kV or greater. There is excessive ozone and other radiation and they make too much noise. They are often structurally weak where them is insulation between electrodes.

[0005] There are rare gas discharge lamps having at least one inside and one outside electrode. One such arrangement is shown is Japanese Patent Publications No. 7-272694 and 8-508363. This arrangement uses an elongated internal electrode. The external electrode is grounded. Radiation noise is reduced and there is no problem of insulation between electrodes. However, sealing of the internal electrode is difficult and it is expensive to manufacture. The amount of luminescence is less than for lamps having only external electrodes.

[0006] Another lamp arrangement is shown In Japanese Patent Application No.10-139751. Voltage is applied between a pair of internal electrodes, and an external electrode formed the longer side of the transparent discharge vessel. The pair of internal electrodes are at the same potential and are fixed at respective ends of the long and slender transparent discharge vessel. The inside electrode structures are easy to manufacture and therefore the cost of such lamps is reasonable.

[0007] However, for presently known lamp arrangements having an external electrode there are some operational difficulties. The temperature of the rare gas becomes too hot, the radiation efficiency of the ultraviolet rays from discharge is too low, and the amount of luminescence saturates as service power increases. Also, luminescence declines immediately after the lamp is started.

[0008] Also there is a tendency for a minute discharge to occur between the circumferential part of the external electrode and the external surface of the transparent discharge vessel. This discharge generates ozone, which is offensive under certain circumstances. Also, the surrounding glass is heated locally by such discharge which can damage the glass, such as soda lime glass and other glasses having alkali metals in them.

[0009] The discharge is stabilized and it is hard to produce the flickering of the discharge, and even when the service power is large, the radiation efficiency of present invention of the ultraviolet ray is good, and It aims at providing the rare gaseous discharge lamp equipped with the external electrode with which the optical output is seldom saturated, the rare gaseous discharge lamp lighting circuit using this, and the light device.

SUMMARY OF THE INVENTION

[0010] This invention provides new rare gas discharge arrangements, a method of operating rare gas discharge lamps, and lighting equipment utilizing such lamps.

[0011] Rare gas discharge lamps, according to the invention, can be operated at a voltage of less than 2 kV to minimize discharge through the atmosphere and the amount of ozone thus produced. Such operation also minimizes operational noise. Even though they are operated at a lower voltage than that used for conventional lamps of this general type, our lamps provide adequate luminescence. Our lamps can be operated with either a sine wave or pulse driving power.

[0012] The invention is based on a recognition that it is appropriate to consider electrostatic capacity of the lamp arrangement in its design. Our rare gas discharge lamp is generally of smaller diameter (less than 15 mm) than known lamps of this general type (typically 20-30 mm).

[0013] We use D (measured in mm) to denote the outside diameter of the discharge vessel. It's thickness (measured in mm) is denoted by t, and it's dielectric constant is denoted by ε. According to the invention, the lamp structure must have at least one external electrode

and must satisfy the following equation:

$$0.01 < t / (D \cdot \varepsilon) < 0.05.$$

[0014] Various embodiments of the invention will be described in detail with reference to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The invention will be described in more detail below with reference to the following figures:

FIG. 1 is transverse cross section showing a first embodiment of a rare gas discharge lamp according to the invention;
FIG. 2 is a foreshortened vertical section view of the lamp shown in Figure 1;
FIG. 3 is a graph which shows how flicker is affected by the relationship among outside diameter D, thickness t, and dielectric constant ε;
FIG. 4 is a schematic representation illustrating flickering:
FIG. 5 is a graph which shows the effect on luminance of service power per unit length;
FIG. 6 is a graph which shows how luminance and lamp wall temperature change with time after lamp starting;
FIG. 7 is a graph which shows the effects of pressure of the discharge medium on flickering and relative luminescence efficiency;
FIG. 8 is a graph which shows a relation between lamp (per electrode surface area) and maintenance of luminance;
FIG. 9 is an enlarged sectional view showing an ultraviolet ray luminescence domain explaining the mechanism of rare gas discharge during "negative phase";
FIG. 10 is an enlarged sectional view showing an ultraviolet ray luminescence domain explaining the mechanism of rare gas discharge during "positive phase";
FIG. 11 Is a elevational view showing a second embodiment of a rare gas discharge lamp according to the present invention;
FIG. 12 is an enlarged view of an external electrode;
FIG. 13 is an enlarged sectional view showing an ultraviolet ray luminescence domain;
FIG. 14 is a graph which shows a relation between frequency and minute discharge start voltage in the atmosphere;
FIG. 15 is a graph which shows the relation between applied voltage and electrostatic capacity for a predetermined lamp current when the area of the external electrode and the lighting frequency are fixed;
FIG. 16 is a elevational view of a fourth embodiment of a rare gas discharge lamp according to the invention;
FIG. 17 is a enlarged side elevation view;
FIG. 18 is a transverse cross section of a fifth embodiment of the rare gaseous discharge lamp according to the present invention;
FIG. 19 is a schematic diagram of a first embodiment of a rare gas discharge lamp lighting circuit according to the present invention;
FIG. 20 is a drcuit diagram of a second embodiment of a rare gas discharge lamp lighting circuit according to the present invention;
FIG. 21 is a circuit diagram of a third embodiment of a rare gas discharge lamp lighting circuit according to the present invention;
FIG. 22 is a circuit diagram of a fourth embodiment of a rare gas discharge lamp lighting circuit according to the present invention;
FIG. 23 is a graph showing the relation of the heating power of the internal electrode, and starting voltage for the forth embodiment of the discharge lamp lighting circuit;
FIG. 24 is a sixth embodiment of a rare gas discharge lamp according to the present invention and a fourth embodiment of a rare gas discharge lamp lighting circuit, shown in partial broken elevational view and the circuit diagram;
FIG. 25 is a sectional view showing a first embodiment of lighting equipment according to the present invention, this embodiment being particularly well suited for down light type back lighting;
FIG. 26 is a sectional view showing a second embodiment of lighting equipment according to the present invention;
FIG. 27 is a sectional view showing the scanner as the third embodiment of lighting equipment according to the present invention;
FIG. 28 shows a fourth embodiment shown in broken elevational view of lighting equipment according to the present invention, this embodiment being particularly well suited for use as a video display;

[0016] Preferred embodiments of the invention will be described with reference to the accompanying drawings. Throughout the drawings, like reference numerals designate like or corresponding parts or elements. Duplicative description will be avoided as much as possible.

DETAILED DESCRIPTION OF THE INVENTION

[0017] Before describing the specific embodiments with reference to the figures, some general description is provided. Unless otherwise specified, definitions terms and technical meanings used throughout this document are as follows:

Transparent Discharge Vessel

[0018] The discharge vessel can be formed in various

ways and from various materials. One typical vessel is a long and slender (more than twice the length its diameter) glass bulb sealed at both ends. For the type of lamps being described In this patent, the vessel can be completely transparent or it can have a transparent window from which light can emit The vessel could also be formed from a translucent ceramic or other suitable materials having an appropriate dielectric constant, such as, for examples, flexible glass and half-hard glass, hard glass, quartz glass, etc.

[0019] The lamp must have a suitable electrostatic capacity which is a function of vessel outside diameter D (mm), thickness t (mm), and dielectric constant ε according to the equation:

$$0.01 < t / (D * \varepsilon) < 0.05.$$

[0020] The diameter itself is not restricted. In order to radiate heat effectively it would be desirable for the outside diameter to be large. However, a large diameter causes the lamp to have a poor starting characteristic. The range of 10-18mm is suitable, and the range of it is 12-18mm is more preferable.

[0021] Various vessel shapes can be used. It can be tubular or bent in one or more places, for examples, "U"-shaped, ring, and half-circle. Because the vessel may be bent Into an asymmetrical shape, the overall outside diameter may be 50-500 mm or even a greater range.

Discharge Medium

[0022] Suitable discharge media includes rare gases xenon, neon, argon, krypton, etc. Halides of the rare gas and the halogen simple substances other than the rare gas may be added. Suitable halogens include iodine, bromine, and chlorine.

[0023] Upon discharge, the rare gas, such as xenon, generates ultraviolet light which in tum excites a phosphor layer in the vessel. The phosphor layer then generates useful visible light which is emitted from the lamp. The pressure of the rare gas is not restricted. However, a it should generally be 100 or less k Pa and preferably 20-60 k Pa.

Pair of Electrodes

[0024] The present invention requires at least one pair of electrodes but it can include additional electrodes. Additional electrodes or pairs of electrodes can be used. At least one electrode Is external to the discharge vessel (both may be external). The external electrode is formed on the outside surface of the vessel or in close proximity to it.

[0025] The external electrode can be made of metal foil, conductive paint film, metal vapor coating film, transparency electric conduction film, metal mesh, comparatively thin metal boards, etc., such as the aluminum, or other suitable materials.

[0026] As used herein, 'metal mesh' refers to any structure that allows ultraviolet rays and/or visible light to pass, such as a wire nit like a net or metal having many holes punched therein.

[0027] When the electrode arrangement includes an internal electrode, the internal electrode is often of a generally cylindrical shape having a length corresponding to that of the discharge vessel. It can have a board-like or line-like form. The internal electrode can be made of a conductive metal, for example, nickel, stainless steel, tungsten, molybdenum, etc.

[0028] The internal electrode may be formed as a mesh structure. When the internal electrode is a mesh structure, ultraviolet ray generated from the rare gas discharge can pass the mesh. If phosphor is formed on inside surface of the transparent discharge vessel, visible light can be easy to make.

[0029] The internal electrode is fixed so as to have a predetermined position within the transparent discharge vessel so that the electrical properties of the lamp remain constant and in order not to damage the phosphor layer etc. Typically the ends of the internal electrode are fixed to the transparent discharge vessel.

[0030] The internal electrode may not be uniform or symetrically placed within the vessel although it is common for it to be located on the main axis of the transparent discharge vessel.

[0031] Furthermore in order to fix the internal electrode in the transparent discharge vessel, again, various known seal means, such as flare seal, bead seal, and pinch seal, can be chosen.

Other Composition

[0032] Some preferred embodiments of this invention utilize an aperture formed in the discharge vessel. A reflective film is formed at portions of the discharge vessel other than at the aperture. This helps to increase the amount of light emitted from the aperture and in a specific direction. This is an advantage in certain lamp applications, such as for example, a copy machine lamp that illuminates a page to be copied. The reflective film can be formed inside or outside of the vessel. If it formed on the inside of the vessel, it can be formed by particles, such as high oxidization titanium deposited on the inner surface of the vessel. Whatever structural arrangement is used, there must remain the ability for ultraviolet rays to reach the phosphor layer to excite them to produce visible light. Thus any structures positioned between positions whereat ultraviolet rays are generated and the phosphor layer (wherever it may be formed) must be permeable to ultraviolet rays. in using outside the lamp the ultraviolet ray generated by the rare gas discharge. Typically, the phosphor layer is formed inside of the discharge vessel. In an aperture type lamp arrangement, the phosphor layer would not be formed at the aperture which is allowed to remain transparent so as to emit vis-

ible light.

[0033] Various phosphors can be used depending on the particular application for which the lamp is made. For back light equipment, and automobile meters, a phosphor of white light systems, such as the rare earth phosphor of the three (3) wave luminescence type or the halo phosphate phosphor, can be used. For a color display, phosphors which emits red, green, and blue primary color lights can be used. Examples include phosphate phosphor ($LaPO4:Ce3+$, $Tb3+$) of the rare earth or the green like $BaAl12O19:Mn$ can be used for reading. Other substances can be combined with phosphors as the application requires.

[0034] Under certain conditions it is desirable to form a protection film on the inside of the transparent discharge vessel. This film can be made from alumina particles, etc. If a protective film is used, the phosphor layer is formed inside of the protection film.

Operation of the Invention

[0035] This invention takes into consideration the electrostatic capacity of the structural configuration including the discharge vessel and its associated parts. By taking into consideration the electrostatic capacity it is possible to operate lamps having at least one external electrode at a lower voltage than is necessary with known lamps. Operating with a lower voltage reduces the amount of ozone produced and provides other operational advantages. There is still sufficient ultraviolet radiation generated to excite the phosphor layer and provide visible light.

[0036] During an ozone discharge, a streamer discharge occurs across a gap in which there is dielectric. Inside the streamer there is an electrolytic dissociation from the cathode to the anode. Xenon emits only atomic luminescence (147 nm wavelength) when xenon pressure is low. But when the pressure is over 10 kPa, xenon emits luminescence at 172 nm .

[0037] The electrostatic capacity C of the transparent discharge vessel is a current-limiting impedance of value 1 $1(2\pi f * C)$, which limits tcauses an ozonaizer discharge to shifts at the arc discharge in the nature of discharge and prevents it from concentrating at a specific point.

[0038] The value of the current-limiting impedance is inversely proportional to frequency. For high frequency lighting the impedance becomes too small too much and it may stop acting as a current limiter. It is possible that in the case of a ramp driving voltage lamp current will change and the discharge will become unstable.

[0039] We configure our lamp so as to have a clearly defined relationship among certain parameters: outside diameter D (measured in mm) of the discharge vessel, thickness t (measured in mm) of the discharge vessel, and dielectric constant ε. These parameters must be related according to the equation below. If the equation is satisfied, the electrostatic capacity causes there to be a sufficient level of current-limiting impedance.

$$0.01 < t/(D * \varepsilon) < 0.05$$

Adhering to this relationship causes there to be formed a constant current circuit which stabilizes discharge. However, if the electrostatic capacity becomes too large, and the current-limiting impedance becomes too small, discharge current will be too high. If electrostatic capacity becomes too small, and current-limiting impedance becomes too large, discharge current will not flow.

[0040] By constructing a lamp in accordance with these requirements and in accordance with the conditions set forth below, the amount of luminescence can be increased with respect to known lamp arrangements and that luminescence has a distribution that is quite uniform. Flickering is minimized.

[0041] Lamp current density ID (mA/cm^2) is represented by rated lamp current (mA) divided by the area (cm^2) of the external electrode when pressure of the rare gas is P (Pa) is expressed by the following relationship.

$$-0.2666 * P + 410.8451 > ID > 0.1333 * P - 2.0132$$

[0042] Rare gas of 13332.2 - 53228. 8 Pa-is enclosed within the discharge vessel.

[0043] The external electrode forms a ring-like portion around the discharge vessel which counters each internal electrode. (Flickering control of the brightness)

[0044] Use an external electrode having a central part width larger than the width at its. (Equalization of the luminescence distribution)

[0045] A transparent insulated covering can be used to enhance insulation between electrodes. This could be a transparent heat shrinkage tube.

[0046] Typically, known lamp arrangements are operated with a rectangular pulse wave. Our lamps can be operated with such driving power. However they can also be operated with a sine wave or half wave rectified sine wave. Doing so minimizes radiation noise and prevents significant decreases of light output. A high frequency sine wave AC voltage can be applied, and the radiation noise can be further reduced.

[0047] Various types of driving voltages and wave shapes can be used, such as, for examples, pulse, half wave rectified sine wave, AC symmetrical AC, asymmetrical AC which has a direct current superimposed on a sine wave AC, pulse, etc. The frequency of the driving should be 1 kHz. or more. Although a preferred range is 4 kHz. - 1 MHz. Generally 30 kHz. or more is especially desirable and flickering is significantly reduced at 100 kHz or more. Luminescence efficiency improves using an asymmetrical wave. After glow Is produced In the pause between voltage wave.

Insulation becomes easy and radiation noise decreases if the external electrode is grounded. The rare gas dis-

charge lamp and the high frequency power supply can be provided as an integrated unit or they can be separately provided. Dimming can be carried out using pulse width modulation (PWM).

[0048] The outside diameter of the transparent discharge vessel is 12-18mm, the service power per unit length is 0.1-0.3 (W/mm) and the pressure- of; discharge medium is 20-60 kPa. By limiting the outside diameter of the transparent discharge vessel to 12-18mm, the electrostatic capacity can be made small enough so as to not prevent starting. The service power per unit length 0. 1-0.3 (W/mm) prevents over heating of wall temperature, and the optical output is seldom saturated.

[0049] Luminescence efficiency can be made high by specifying the pressure of the discharge medium to be in the range of 20-60 kPa. However, if the pressure exceeds 60 kPa, flickering (Intense change of the optical output of the short cycle) becomes remarkable.

[0050] It is desirable that the frequency of the applied voltage be 100kHz or more. This helps to reduce flickering. It is also advantageous for there to be a certain relation between lamp current I (measured in A) and external electrode surface area S (mm^2) as follows:

$$I / S < 0.5\ (A/mm^2)$$

[0051] If the diameter of the internal electrode is small, the discharge medium sputters and the temperature of the internal electrode rises. This can causes problems such as the melting of part such as a case. The external electrode is formed over the entire transparent discharge vessel except the portion acting as a light aperture. Radiation noise can be sharply reduced by grounding the external electrode. This also makes insulation between electrodes easy.

[0052] The use of any Internal electrodes tends to reduce light output compared with the use of only external electrodes. However, the amount of luminescence can be increased by doing the following.

1. Make the internal electrode into the shape of a board.
2. Make the internal electrode into the shape of a mesh.
3. Heat the internal electrode to produce electronic radiation.
4. Form a dielectric layer in the surface of the internal electrode.

[0053] The internal electrode is fixed at least one end to the transparent discharge vessel. The other end may be free. Both ends may be made into a structure which fixes both ends to the discharge vessel.

[0054] The rare gas discharge lamp constructed according to the present invention can be operated without the minute discharge when applying an AC voltage or a pulse voltage having a peak of 2 kV or less between electrodes. The minute discharge changes with the amount of electrostatic capacity per unit area between the inside of the transparent discharge vessel and the external electrode. If the electrostatic capacity become too large, the minute discharge will be generated even when a low voltage is applied. Therefore, to prevent minute discharge, the electrostatic capacity should be kept small. The electrostatic capacity per unit area of the transparent discharge vessel changes with the quality of the material and thickness which influence the permitivity of the transparent discharge vessel. By specifying electrostatic capacity to be as small as possible, minute discharge start voltage can be made high and the rare gas discharge lamp will not have minute discharge even when it is operated at a voltage peak of 2 kV.

[0055] Although lamp current can be increased by increasing the applied voltage, it is not practical to do so.

[0056] It is advantageous for the applied voltage to be a sine wave. This tends to reduce noise. However, by using a pulse voltage such as a half wave rectified sine wave AC, light output can be increased due to after glow. However this form of driving voltage generates more noise. However, it is more desirable than using a rectangular wave.

[0057] The electrostatic capacity per unit area between the inside of the transparent discharge vessel and the external electrode is 0.03 ($\mu F/m^2$). The electrostatic capacity can be calculated from relative permitivity and thickness of the area of the transparent discharge vessel which becomes covered by the external electrode. Actual values can be measured with an LCR meter.

[0058] The rare gaseous discharge lamp has a phosphor layer formed on the inside surface of the transparent discharge vessel so that it may be excited by the rare gas discharge that occurs in the vessel between electrodes (external only or internal and external). The lamps have at least one aperture for light to be emitted from the vessel. Although the length of the transparent discharge vessel is not restricted, a good length is 200-500 mm and, generally, the outside diameter is 6-8mm, but suitably 20mm or less. The external electrode should be formed along the longer side of the vessel and can be constituted by as many as 10-20 pieces.

[0059] The aperture may be the one long and slender continuous aperture or It may be a plurality of smaller ones for emitting light corresponding to localized discharges. Multiple pairs of electrodes can be provided for selecting particular discharge areas. This can be useful for generating light of different colors, mixing colors, and providing a video display.

[0060] Connection with the power supply will now be described for the internal/external electrode arrangement. The internal electrode is connected to one pole of the power supply and the external electrode is connected with the other power supply pole. The rare gas discharge occurs between the domains of the internal electrode and the external electrode. If there is an aperture

associated with each external electrode, light can be controlled simply by electrically selecting the desired external electrode and aperture. Two or more external electrodes can be connected to simultaneously to achieve desired effects. For multiple internal electrode arrangements, they can be switched as well.

[0061] Dimming can be achieved by modulating with a frequency lower than lighting frequency.

[0062] By forming many rare gas discharge lamps in a matrix, it is enabled to perform various picture displays by providing a driving arrangement that can cause individual elements of the matrix to fire. Color displays can be made by selecting phosphors for individual elements corresponding to primary colors that can be mixed to make other colors.

[0063] Generating ozone can be controlled while preventing luminescence by the leakage discharge which originates in the electrostatic capacity of the lighting circuit by regulating the frequency and the peak value of the electrostatic capacity by the external electrode, and the applied voltage in the predetermined range. In addition a cover board such as a shrink wrap can be applied over and between electrodes. The peak value of voltage should be 2 kV or less, and the AC frequency should be 30 kHz. or more.

The rare gaseous discharge lamp can be used without any extra current-limiting impedance. The electrostatic capacity should be sufficient. The driving frequency of 30 kHz. or more should not be audible. It is practical to use semiconductor devices generate the driving frequency. A high frequency inverter can be used as the power supply. Half wave rectification of the high frequency output may be carried out, and pulse voltage may be formed in the pulse lighting case.

[0064] The electrostatic capacity C is sufficient between the inside of the transparent discharge vessel and the outside for a lamp current I (measured in amps A) to flow using a lighting frequency f (Hz.) satisfying the equation

$$C > I / (4\pi rf * 10^3) \text{ (F)}$$

The value of electrostatic capacity C which becomes settled with the external electrode of the rare gaseous discharge lamp for not generating the minute discharge and the transparent discharge vessel to predetermined lamp current and predetermined lighting frequency is specified.

[0065] What is necessary is just to have the above-mentioned equation the sufficient electrostatic capacity, in order to flow a predetermined lamp current without the minute discharge's generating the rare gaseous discharge lamp in the lighting case with frequency f Hz. since the minute discharge is produced if the applied voltage is 2kV or more. This invention provides lamps, methods of operating the lamps and various lighting equipment utilizing the lamps. The equipment includes, for example, back light equipment, scanner, office automation equipment, display equipment, etc., back light equipment including both the "down" light type and the "side" light type.

[0066] Embodiments of the present invention will be further described with reference to the drawings.

[0067] Fig.1 is a transverse cross section showing a first embodiment of a rare gaseous discharge lamp according to the invention. Fig.2 is a foreshortened vertical section view of the lamp shown in Fig. 1.

[0068] A transparent discharge vessel 1 has associated with it a phosphor layer 2, an external electrode 3 and an internal electrode 4. An adhesive layer 5 made of polyamide holds external electrode 3 to the outer surface of vessel 1. Thickness of the adhesive layer 5 is 0.01 mm. Transparent discharge vessel 1 has an outside diameter D of approximately 15 mm and thickness t of approximately 2.0 mm. It has a dielectric constant ε. Vessel 1 is a long and slender glass bulb made of borosilicate glass. Phosphor layer 2 is formed in the inside of vessel 1 except at a portion thereof forming an aperture 1a for emitting light. Vessel 1 contains 30 kPa of xenon, a rare gas. Phosphor layer 2 and adhesive layer 5 are not shown in Fig. 2.

[0069] External electrode 3 is advantageously made of aluminum foil, but other suitable materials could be used. It is formed on the external surface of vessel 1 so that the vessel is surrounded except at aperture 1a which constitutes about 20% of its area.

[0070] Internal electrode 4 is made of nickel stick and has a diameter of approximately 2 mm. Other suitable materials could be substituted for the nickel. Internal electrode 4 is fixed at both ends of vessel 1.

[0071] A rare gaseous discharge lamp in accordance with the structure described can be operated by driving it with the appropriate signals. In one such driving arrangement the external electrode 3 is grounded. A sinusoidal or pulse signal of preferably less than 2 KV is applied across the electrode so that the lamp draws about 200 mA of lamp current. It can be dimmed by pulse width modulating the driving signal at 50 kHz. A lamp having a structure according to this invention and operated in this manner has sufficient surface area to dissipate the heat that will be generated.

[0072] In a conventional lamp the impedance due to the electrostatic capacity of the transparent discharge vessel is small. Current flows to its peak value rapidly when voltage is applied. This causes flickering. However, in our invention, by properly selecting the various dimensions for the lamp and their relationships to the dielectric constant the impedance is controlled to be within a certain range. This minimizes flickering and noise and allows the lamp to be operated with a driving voltage under 2 kV, and preferably about 1.5 kV.

[0073] Fig.3 is a graph showing the effect on flicker of the relationships among outside diameter D mm of the transparent discharge vessel, thickness t mm, and dielectric constant ε. The horizontal axis represents the ra-

tio t / D * ε and the vertical axis represents amount of flickering of the discharge as a percentage (%). t / D * ε is in inverse proportion to the electrostatic capacity of the lamp. As t / D * ε becomes large, flickering decreases. The lamp operation is considered to be satisfactory if the flickering is 5% or less.

[0074] One suitable example (among many) uses a vessel 1 having an outside diameter of 12 mm, a length of 300 mm, filled with xenon at a pressure of 30kPa and operated at 1.5 kV.

[0075] Fig.4 is a enlarged light output wave form chart explaining concept of flickering that occurs during operation of a rare gaseous discharge lamp. The horizontal axis represents time and the vertical axis represents amount of light output (arbitrary scales), respectively. The rate of flickering is the difference between peak and average values of light output. It is advantageous to minimize flickering.

[0076] Fig.5 is a graph which shows the relation of service power per unit length of the discharge vessel and the relative luminance output of the lamp.

[0077] The horizontal axis represents service power in W/mm and the vertical axis represents relative luminance as a percentage (%) for various situations. The curve A data is for a vessel having an outside diameter of 12 mm, curve B data is for a vessel having an outside diameter of 15 mm, and curve C data is for a vessel having an outside diameter of 18 mm. As service power increases luminescence tends to saturate. However the larger diameter tube seems to have a larger range of luminescence before saturating. If the outside diameter is selected to be in the range of 12-18mm of the outside diameters, optical output can be controlled by controlling service power in the range of 0. 1-0.3 (W/mm).

[0078] Fig.6 is the graph showing the relation of relative luminance as a function of time after starting the lamp. It also plots the wall temperature of vessel 1. The horizontal axis represents time (min) from starting the lamp. The vertical axis left side shows relativity luminance (plotted in curve D) as a percentage (%) and the vertical axis right side shows wall temperature (plotted in curve E) in degrees centigrade. The lamp used for measuring this data was operated for 5000 hours. It had a diameter of 12mm, a length of 300 mm, was filled with xenon at a pressure of 30 kPa and was operated with a service power of 50 W (about 0.17 W/mm).

[0079] Fig.7 is the graph which shows the relationship of the pressure of the discharge medium (plotted on the horizontal axis in kPa), to both flickering (curve G plotted on the right vertical axis as a percentage %) and relative luminescence efficiency (curve F plotted on the left vertical axis as a percentage %). A suitable range for discharge medium pressure is 20-60kPa to obtain reasonable values of luminescence efficiency while minimizing flicker.

[0080] Fig.8 is the graph which shows the relation of lamp current per surface area of the internal electrode vs. maintenance rate of luminance. The horizontal axis shows the ratio of lamp current I to surface area S (A/mm^2), and the vertical axis shows maintenance rate of luminance (%). If I/S becomes greater than 0.5 A/mm^2 the maintenance rate of luminance falls abruptly. A larger electrode surface area helps to achieve an I/S less than 0.5 and therefore achieve a luminescence percentage that is high.

[0081] Figures 9 and 10 help to explain the operation of a rare gaseous discharge lamp. They are enlarged sectional views of a principal part of a lamp according to the present invention. The phosphor layer is not shown. Electrons are attracted by external electrode 3 through a plasma which is generated by internal electrode 4 discharging in the presence of xenon inside vessel 1 during a negative phase. These electrons do not penetrate vessel 1 and adhere to the inside of vessel 1, thereby causing it to become negatively charged. External electrode 3 develops a corresponding positive charge.

[0082] There is an electrostatic capacity between the inside and outside of vessel 1. If the internal electrode 4 becomes positive electrons will be attracted to it and electron current will flow toward internal electrode 4, and will return to the power supply. This process of negative phase and positive phase with corresponding current flow back and forth repeats continuously during lamp operation to maintain a rare gas discharge. The power supply "sees" a certain electrostatic capacity based on the various dimensions and dielectric constant of the discharge vessel 1. The discharge causes ultraviolet rays to be emitted which, in turn, strike the phosphor layer (not shown), causing it to emit visible light. This occurs during domain 7 shown in Fig.9 and during domain 8 shown in Figure 10.

[0083] Figures 11-13 show a second embodiment of the invention using a mesh stricture external electrode. Fig.11 is an elevational view. Fig.12 shows an enlarged portion of the external electrode.

[0084] Fig.13 shows the ultraviolet ray luminescence domain.

[0085] Explanation of the common elements already explained in the first embodiment will not be further explained.

[0086] External electrode 3 is a metal mesh structure that covers substantially all of vessel 1. This mesh structure is similar to that of a knitted fabric. The mesh can be made large enough for vessel 1 to be inserted into it and then pulled so that it fits snugly around the vessel. Domain 9 in Figure 13 illustrates the discharge mechanism and generation of ultraviolet rays for causing the phosphor layer to emit visible light. Domain 9 can actually be more effective than domains 7 and 8, shown in Figures 9 and 10 to provide good luminescence.

[0087] A third embodiment of the rare gaseous discharge lamp of the present invention will now be explained. The structural configuration is the same as the first embodiment shown in Fig.1, but various parameters are different. Vessel has a 10mm outside diameter, is

1mm of thick, is made of borosilicate glass and has a length of 300 mm. The discharge medium is xenon at a pressure of 40 kPa. The internal electrode 4 is a nickel stick having a diameter of 1 mm attached at both of its ends to vessel 1 through cobalt glass metal. Phosphor layer 2 is (LaPO4:Ce and Tb), and is formed over 270 degrees of circumference of the vessel, thus leaving an aperture 1a for light to be emitted. The power supply provides a lighting frequency of 30 kHz. and the lamp produces ultraviolet radiation at a wavelength of 172 nm maximum. The phosphor, excited by the ultraviolet radiation generates a green visible light. This light, emitted through aperture 1a is suitable for reading. There will now be an explanation of the relationship of measured start voltage of the minute discharge with lighting frequency.

[0088] Fig.14 is the graph which shows, for this third embodiment, the relation of the lighting frequency (horizontal axis, kHz.) to minute discharge start voltage in the atmosphere (vertical axis, V). As shown, starting voltage is. relatively constant for a wide range of frequencies (100 kHz. to 1MHz.).

[0089] Fig.15 is the graph which shows the relation, for this third embodiment, of applied voltage at the time of predetermined lamp current flowing, to static capacity which is a function of the area of the external electrode, lighting frequency, etc. The fixed lamp current was 170 mA for various lamps having various static capacities. They were operated at a lighting frequency of 50 kHz. and the size of the external electrode was $30*300*10^{-8}$ m^2. Because minute discharge occurs, the applied voltage should not be more than 2000V.

[0090] Fig.16 is an elevational view of a fourth embodiment. Fig.17 is a enlarged side elevation. Reference numerals in common with previous embodiments will not be further explained.

[0091] This embodiment has a different internal electrode arrangement. Internal electrode 4 comprises a pair of cold cathodes 4A and 4B at respective ends of the transparent discharge vessel 1. External electrode 3 has ring-like portions 3a and 3a corresponding respectively to cathodes 4A and 4B. The phosphor layer is not shown. In this embodiment, rare gas discharge occurs uniformly for full length of the transparent discharge vessel.

[0092] Fig. 18 is a transverse cross section of a fifth embodiment of the rare gaseous discharge lamp of the present invention. Reference numerals in common with previous embodiments will not be further explained. This embodiment features only external electrodes. Electrodes 3A and 3B are on opposite sides of aperture 1a.

[0093] Fig.19 is a schematic diagram of a first embodiment of a piece of lighting circuit using a lamp according to the present invention. Reference numerals in common with previous embodiments will not be further explained. The rare gaseous discharge lamp in this embodiment is the same structure as what is shown in Fig. 1. A low frequency AC power supply 11 and a high frequency power supply 12 provide power. The high frequency power supply 12 is typically an inverter having a low frequency input from power supply 11. Power supply 12 rectifies the power from supply 11 and generates a high frequency power with a frequency of 30 kHz. or more having a peak value of no more than 2kV to be applied across the electrodes.

[0094] Fig.20 is a circuit diagram showing a second embodiment of lighting circuit using a rare gaseous discharge lamp according to the present invention. Explanation of the common elements already explained in the first embodiment will not be further explained.

[0095] The rare gaseous discharge lamp is the same structure as shown in Fig.16. The high frequency power supply equipment 12 includes high frequency generating circuit 12a, output transformer 12b, capacitor 12c, and diode 12d. High frequency generating circuit 12a is usually an inverter and generates high frequency AC sine wave voltage having a frequency of about 30 kHz. or more. The end of 2 order volume line of output transformer 12b is Power supply output is coupled to cold cathodes 4A and 4B through capacitor 12c. The external electrode 3 is grounded. In this case ground provides a return path to complete the circuit.

[0096] A positive half wave of high frequency AC voltage is applied between each of the cold cathodes 4A and 4B, and the external electrode 3 through capacitor 12c. The power from this positive half wave causes the lamp to discharge.

[0097] Fig.21 is a circuit diagram showing the third embodiment of lighting circuit using a rare gaseous discharge lamp according to the present invention. The power supply for this embodiment is different. Power supply 12 includes a high frequency inverter which generates a high frequency sine wave. An output of transformer 12b is connected to both of cold cathodes 4A and 4B. The other end of output transformer 12b is connected to external electrode 3 and is also grounded. Radiation noise is reduced with respect to the Figure 20 arrangement.

[0098] Fig.22 is a circuit diagram showing the forth embodiment of the rare gaseous discharge lamp lighting circuit of the present invention. The rare gas discharge lamp is similar to the one shown in Fig. 19. However, this one is operated at 100Torr, has an 8 mm outside diameter, a 317 mm lamp length, and is filled with xenon gas. This embodiment includes internal electrode heating.

[0099] A transformer of power supply 12 includes two output windings 12b and 12c. At the time of lamp starting, a timing switch S1 connects winding 12c to internal electrode 4 through capacitor C1 to provide heating. Capacitor C1 is current-limiting impedance. Timing switch S1 can operate only for a limited time interval after starting by linkage with the timer.

[0100] Fig.23 is the graph which shows the relation of lamp starting voltage (vertical axis, volts) and the heat-

ing power of the internal electrode (vertical axis, watts). The lighting frequency is 28 kHz. The starting time is 10 seconds. The Internal electrode has 8-ohms resistance.

[0101] Fig.24 shows the sixth embodiment of the rare gaseous discharge lamp lighting circuit of the present invention in a broken elevational view and a partial circuit diagram. This embodiment is particularly suitable for use as a display. This device includes three rare gaseous discharge lamps DLR, DLG, and DLB. There are two or more external electrodes 3a, 3b, --, 3n which operate in conjunction with internal electrodes 4 that run the length of transparent discharge vessel 1 to a common feed. Each lamp has an aperture 1a, 1b, -, 1n respectively.

[0102] A phosphor layer of the red luminescence type Is formed on the Inner surface of the transparent discharge vessel 1 of the rare gaseous discharge lamp DLR. Similarly, the phosphor layer of the green luminescence type is formed in the inside side surface of the transparent discharge vessel 1 of the rare gaseous discharge lamp DLG, and a phosphor layer of the blue luminescence type is formed in the inside surface of the transparent discharge vessel 1 of the rare gaseous discharge lamp DLB. Thus, lamp DLR provides a red luminescence, lamp DLG provides a green luminescence, and lamp DLB provides a blue luminescence.

[0103] The three rare gaseous discharge lamps DLR, DLG, and DLB together constitute one color luminescence unit CPLY. This color luminescence unit CPLY will form a number equal to the external electrodes 3a, 3b, --, 3n number of color pic cells.

[0104] Using this structure, leakage of the rare gas discharge due to the electrostatic capacity between each pic cell may be reduced. A cover board 10 made from ceramics is arranged between adjoining external electrodes at a position corresponding to the middle of the internal electrode. The contrast of the display is good and leakage of rare gas discharge between adjacent external electrodes is minimal. Based on the size of the lamp, the cover board 10 may be twisted. As an alternative to the use of a cover board 10, it is possible to merely use a shrinkage part formed in the transparent discharge vessel between adjoining external electrodes.

[0105] Color luminescence unit CPLY is connected to the pole of another side of the high frequency power supply 12 of which one pole is grounded while each internal electrode 4 outputs high frequency voltage in case of the lighting. Each external electrodes 3a, 3b, -, 3n is connected to the other pole of the high frequency power supply 12 through the switches Sa, Sb, -, Sn and grounding, respectively. It operates the thus and each external electrodes 3a, 3b, --, 3n in the state where it was grounded.

[0106] It is possible to mix colors by turning on more than one of lamps DLR, DLG and DLB by closing more than one of the switches simultaneously. For example, by turning on DLR and DLG simultaneously, an observer who was far enough from the lamps would see yellow as the two colored lights mixed. By also controlling dimming of each of the three lamps a rich variety of colors and tones can be achieved.

[0107] Fig.25 is a sectional view showing a down light type back light equipment according to another embodiment of the invention. A rare gaseous discharge lamp' 21 is combined with a reflector 22 and an optical diffusion board 23. Lamp 21 Is of the type shown in Fig.16. Reflector 22 has an inside surface formed as a parabola reflective side and has attached to it a lamp holder 22a. Holder 22a supports the discharge lamp 21 so that it may be located in the focus of the parabola. Lamp holder 22a and reflector 22 conduct heat away from lamp 21 in part through the connection of the lamp's external electrode which tends to generate heat. In addition, the external electrode may be made to contact with other structures that further heat dissipation. Optical diffusion board 23 is attached to the aperture end of the reflector 22. This arrangement can be used for back lighting a liquid crystal display or other objects with or without additional optical elements.

[0108] Fig.26 is a sectional view of another embodiment of lighting circuit according to the invention, This embodiment is particularly well suited for side lighting. Again, elements in common with previous embodiments will not be explained. A rare gaseous discharge lamp 31 is held in place by a lamp holder 32. A light guide board 33 conducts light from lamp 31 which is shown

[0109] in Fig.1. Holder 32 surrounds the discharge lamp 31 and is connected to the edge of light guide board 33. Light from light guide board 33 is uniformly carried out from the front which can be advantageously made of a transparent acrylic resin. Light entering board 33 from the lamp is reflected internally within board 33 and is emitted only at the desired surface for side lighting.

[0110] Fig.27 is a schematic sectional view showing a scanner arrangement in accordance with another embodiment of a lighting device of the present invention. A rare gaseous discharge lamp 41, positioned within a reflector 45 provides light to a document former 44 that is reflected to a photo receiver 42. A signal processor 43 analyzes signals indicative of the light received by photo receiver 42 to form an image of a document in the document former. Document former 44 may include a transparent glass on which a document to be scanned can be placed face down. Reflector 45 reflects light from the rare gaseous discharge lamp 41 outside toward the document former 44. This type of scanner arrangement is well suited for office automation apparatus, such as the copy machine, the image scanner, and facsimile, etc.

[0111] Fig.28 is a broken elevational view of picture display 51 constituting another embodiment of a light device according to the invention. A frame 51b holds color pic cell lamp units 52. Frame 51b has a display side 51a. Picture display 51 has a high frequency power supply, picture control means, etc. which are not shown,

but have already been explained. The color pic cell lamp units 52 include color pic cell lamp units such as CPLY previously described. Picture display 51 can be used to display a video signal, such as a television video.

[0112] While the invention has been described in connection with what are presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. On the contrary, it is intended to cover various modifications and equivalent arrangements Included within the spirit and scope of the appended claims.

Claims

1. A rare gaseous discharge lamp comprising, a discharge vessel, a discharge medium including a rare gas within the vessel, and a pair of electrodes including an external electrode in close proximity with the outer surface of the vessel for causing a discharge to occur inside the vessel, wherein the vessel having at least a portion thereof transparent and having an outside diameter D mm, a thickness t mm, and a dielectric constant ε satisfying the equation

$$0.01 < t / (D * \varepsilon) < 0.05.$$

2. A rare gaseous discharge lamp according to claim 1, wherein the outside diameter D of the vessel is 10 ~ 18 mm and the lamp operates with a service power per unit length of 0.1 ~ 0.3 (W/mm); and pressure of the discharge medium is 20-60 kPa.

3. A rare gaseous discharge lamp as set forth in claim 1, the lamp is driven by a voltage having a frequency of at least 100kHz.

4. A rare gaseous discharge lamp as set forth in claim 1 wherein the pair of electrodes include one internal electrodes and the lamp current I is related to surface area S of the internal electrode as follows:

$$I / S < 0.5 \ (A / mm^2)$$

5. A rare gaseous discharge lamp as set forth in claim 1, wherein the pair of electrodes include one internal electrodes which are driven by an AC voltage having a peak voltage of 2 kV or less.

6. A rare gaseous discharge lamp as set forth in claim 1, wherein the pair of electrodes are include one internal electrodes which are driven by a pulse voltage having a peak voltage of 2 kV or less.

7. A rare gaseous discharge lamp as set forth in claim 1, wherein the vessel has an electrostatic capacity per unit area between the inside thereof and an external electrode of greater than 0.03 ($\mu F/m^2$).

8. A rare gaseous discharge lamp as set forth in claim 1, wherein

   there are two or more external electrodes are along the longer side of the transparent discharge vessel;
   phosphor layers inside side of the transparent discharge vessel can be excited by driving particular combinations of internal and external electrodes; and
   the transparent discharge vessel has apertures for the light to emit corresponding to particular external electrodes, respectively.

9. A rare gaseous discharge lamp lighting circuit comprising, a power supply and a rare gas discharge lamp comprising, a discharge vessel, a discharge medium including a rare gas within the vessel, and a pair of electrodes including an external electrode in close proximity with the outer surface of the vessel for causing a discharge to occur inside the vessel, wherein the power supply providing AC voltage whose frequency is 30 kHz. or more and having a peak voltage of 2kV or less and the vessel having at least a portion thereof transparent and having an outside diameter D mm, a thickness t mm, and a dielectric constant E satisfying the equation

$$0.01 < t / (D * \varepsilon) < 0.05.$$

10. A rare gaseous discharge lamp lighting circuit comprising, a power supply and a rare gas discharge lamp comprising, a discharge vessel, a discharge medium including a rare gas within the vessel, and a pair of electrodes including an external electrode in close proximity with the outer surface of the vessel for causing a discharge to occur inside the vessel, wherein the power supply providing a pulse voltage whose repetition frequency is 30 kHz. or more and having a peak voltage of 2kV or less and the vessel having at least a portion thereof transparent and having an outside diameter D mm, a thickness t mm, and a dielectric constant ε satisfying the equation

$$0.01 < t / (D * \varepsilon) < 0.05.$$

11. A rare gaseous discharge lamp lighting circuit as set forth in claim 9, wherein the electrostatic capacity C between the inside of the discharge vessel and the external electrode is: $C > 1/4\pi f * 10^3$ (F)

Where f is the lighting frequency in Hz.

12. A light device comprising, a light device main part; a power supply mounted in the main part and a rare gas discharge lamp comprising, a discharge vessel, a discharge medium including a rare gas within the vessel, and a pair of electrodes including an external electrode in close proximity with the outer surface of the vessel for causing a discharge to occur inside the vessel, wherein the power supply providing AC voltage whose frequency is 30 kHz. or more and having a peak voltage of 2kV or less and the vessel having at least a portion thereof transparent and having an outside diameter D mm, a thickness t mm, and a dielectric constant ε satisfying the equation

$$0.01 < t / (D * \varepsilon) < 0.05.$$

13. A light device set forth in claim 12, further comprising a heat dissipater and wherein the external electrode is thermally connected to the heat dissipater.

14. A rare gaseous discharge lamp lighting circuit as set forth in claim 9, wherein the power supply provides an AC wave with a superimposed DC component.

15. A rare gaseous discharge lamp lighting circuit as set forth in claim 9, wherein the power supply applies power for heating the internal electrode at least upon starting the lamp.

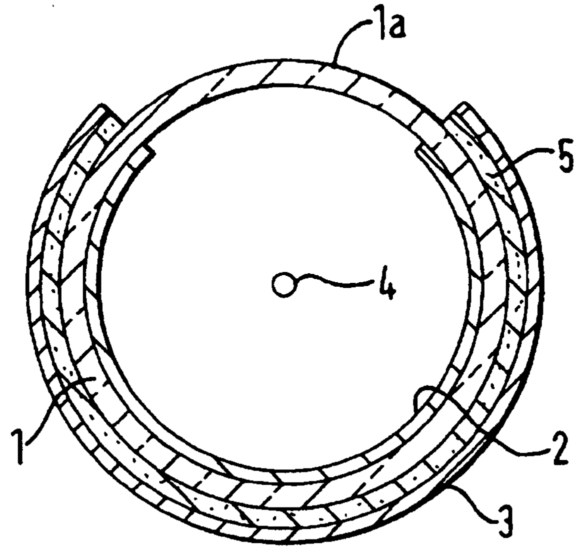


FIG. 1

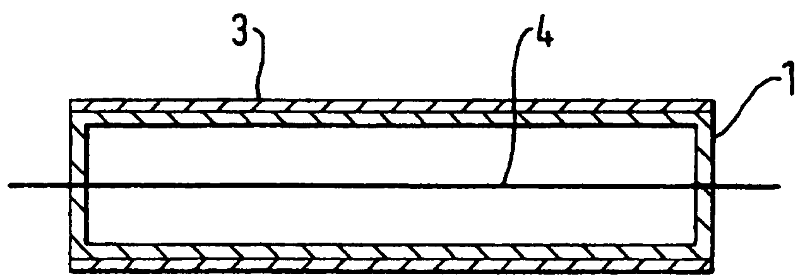


FIG. 2

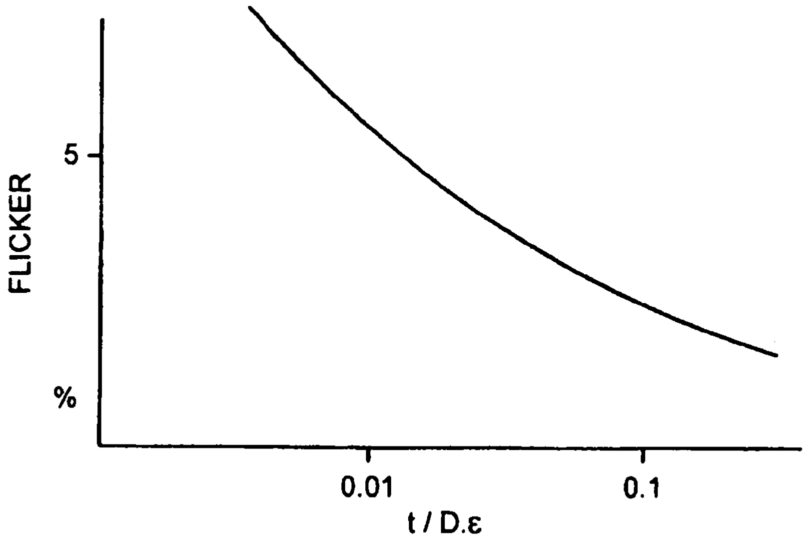


FIG. 3

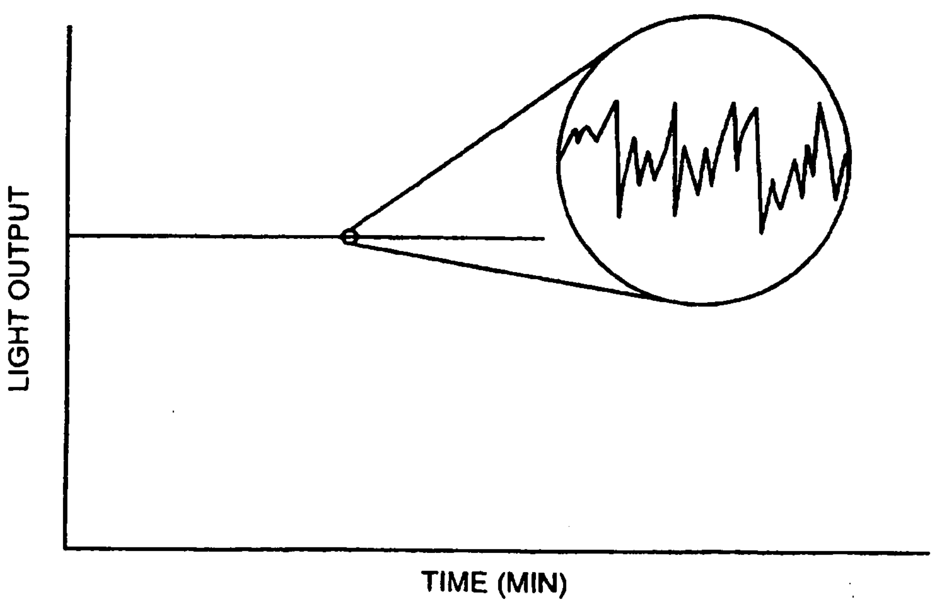


FIG. 4

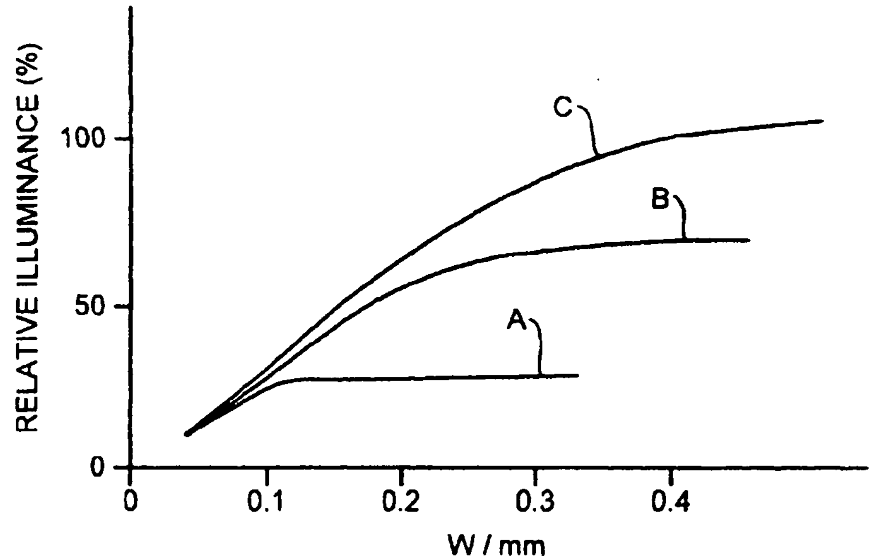

RELATIVE ILLUMINANCE (%)
100
50
0
C
B
A
0
0.1
0.2
0.3
0.4
W / mm

FIG. 5

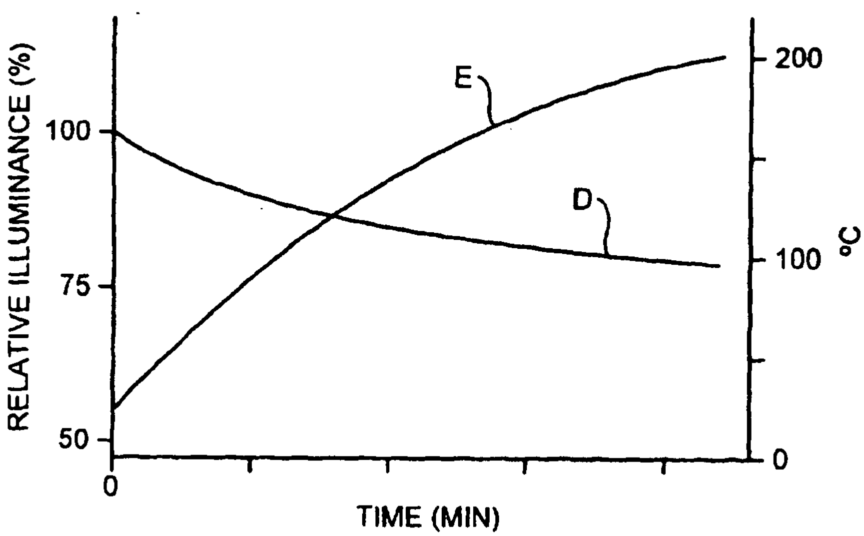

RELATIVE ILLUMINANCE (%)
100
75
50
E
D
200
100
0
°C
0
TIME (MIN)

FIG. 6

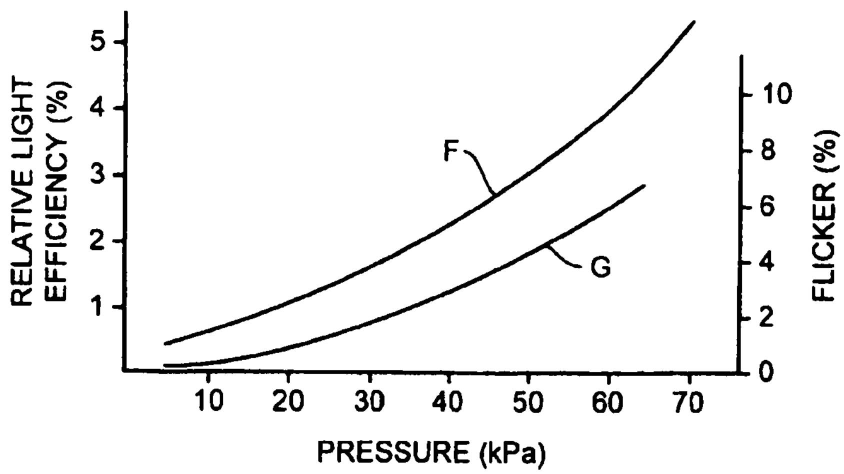

RELATIVE LIGHT EFFICIENCY (%)
5
4
3
2
1
F
G
10
8
6
4
2
0
FLICKER (%)
10 20 30 40 50 60 70
PRESSURE (kPa)

FIG. 7

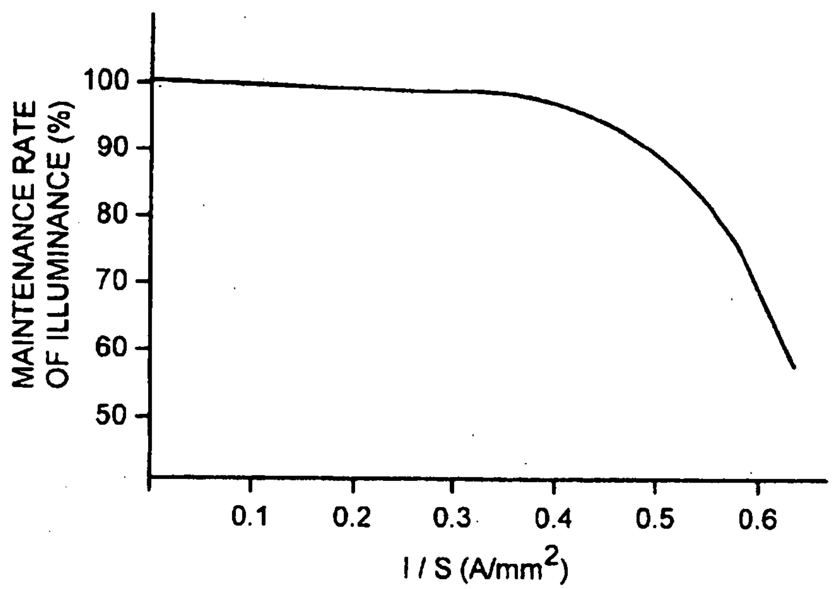

MAINTENANCE RATE OF ILLUMINANCE (%)
100
90
80
70
60
50
0.1 0.2 0.3 0.4 0.5 0.6
I / S (A/mm²)

FIG. 8

FIG. 9

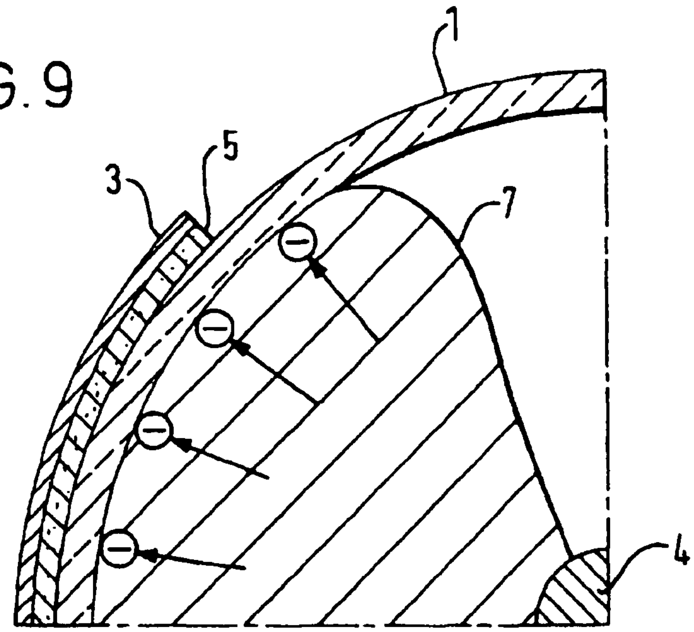
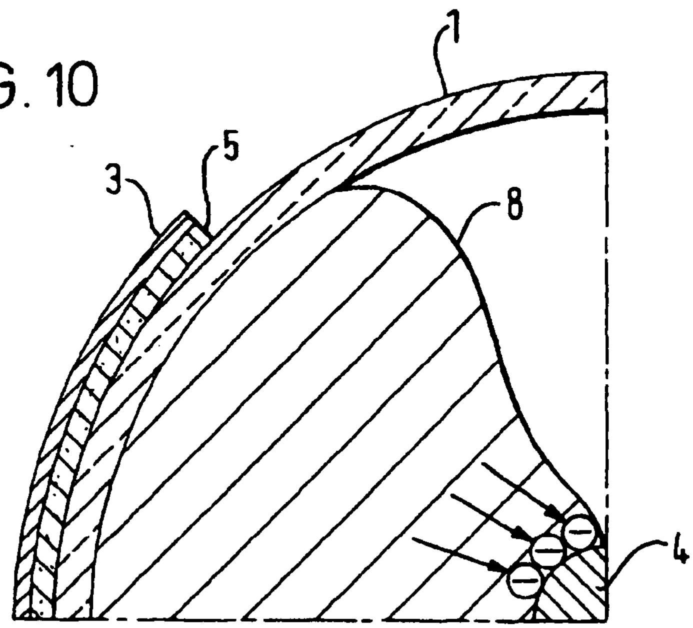


FIG. 10



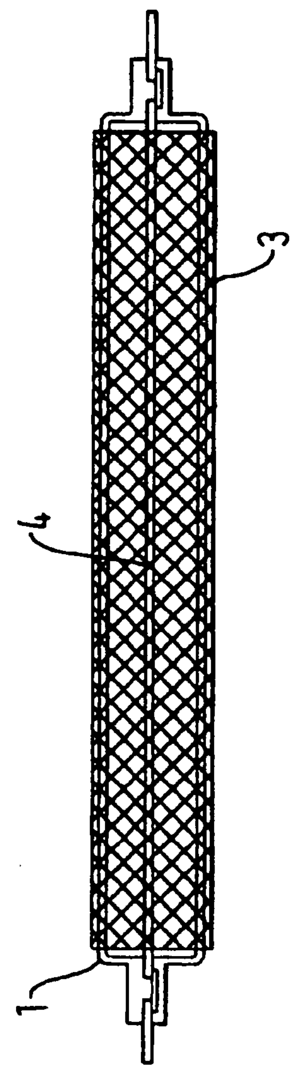


FIG.11

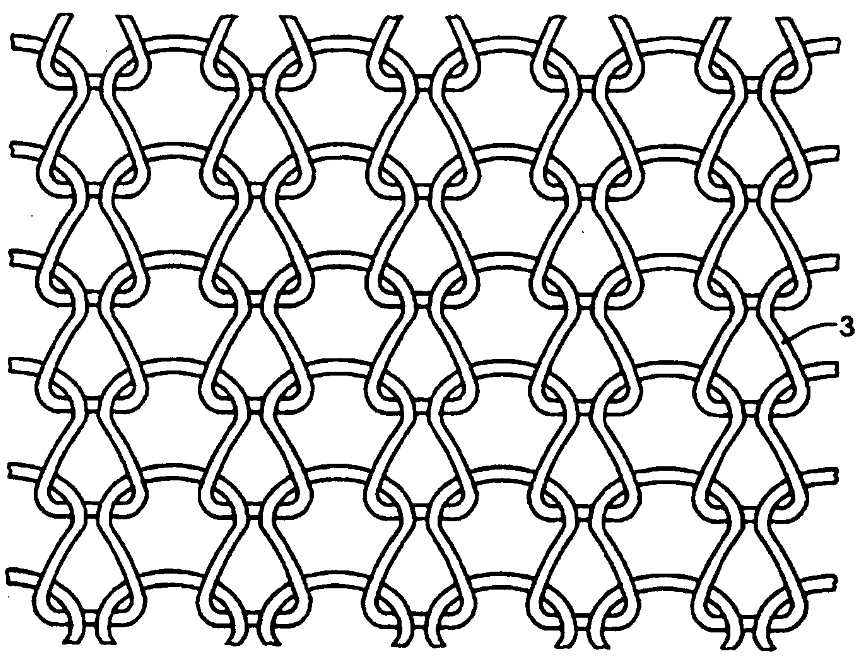


FIG.12

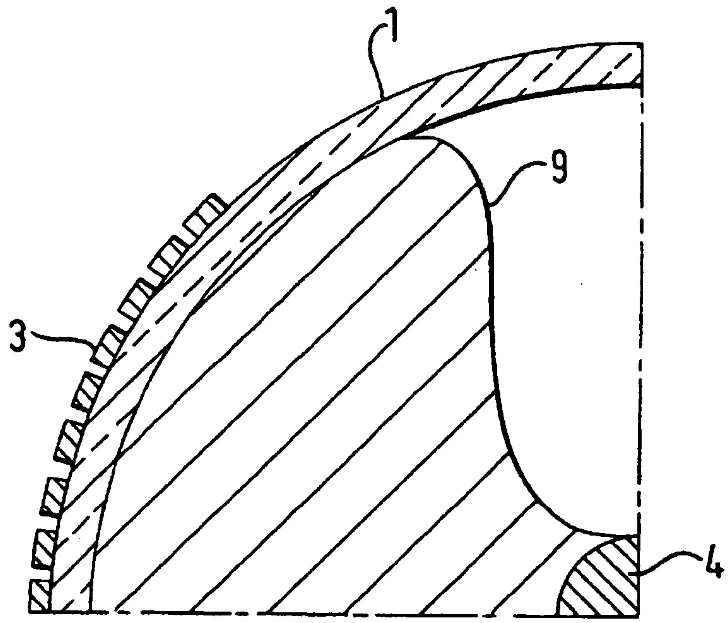


FIG. 13

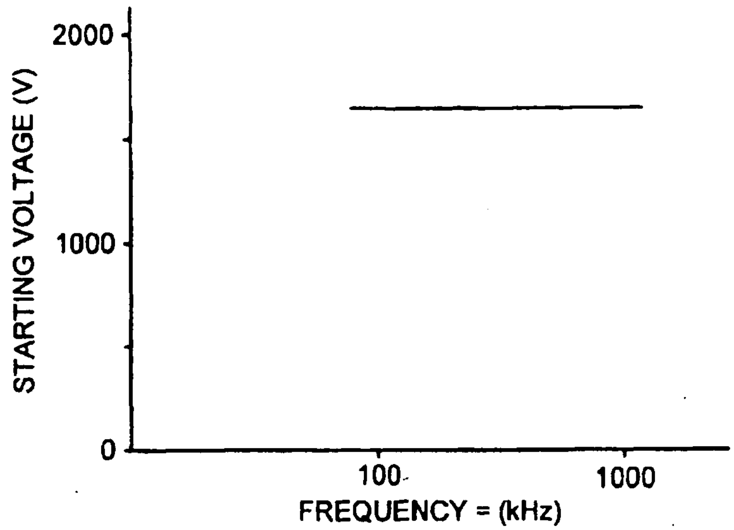

2000
1000
0
STARTING VOLTAGE (V)
100
1000
FREQUENCY = (kHz)

FIG. 14

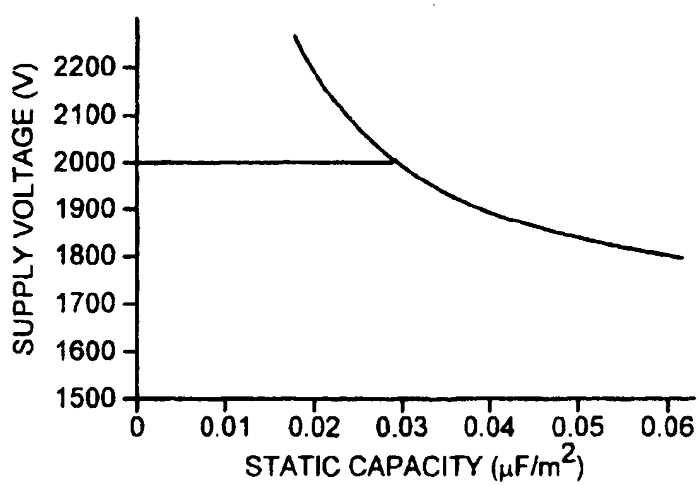

2200
2100
2000
1900
1800
1700
1600
1500
SUPPLY VOLTAGE (V)
0
0.01
0.02
0.03
0.04
0.05
0.06
STATIC CAPACITY (μF/m2)

FIG. 15

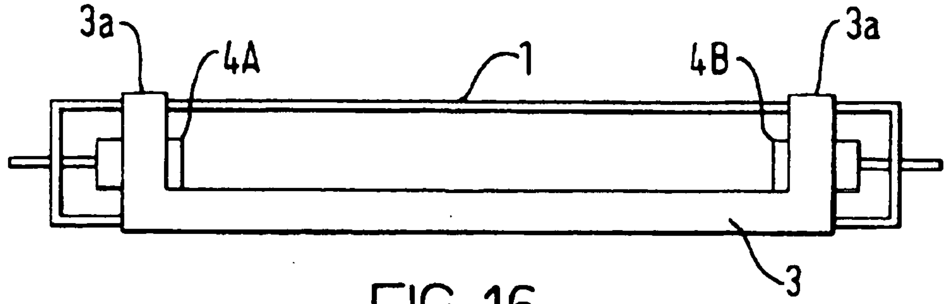


FIG. 16

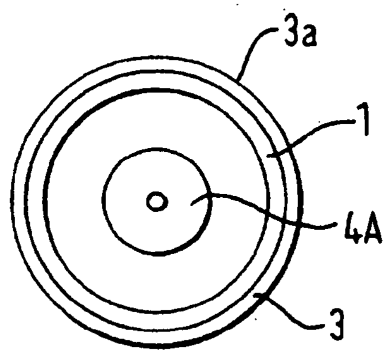
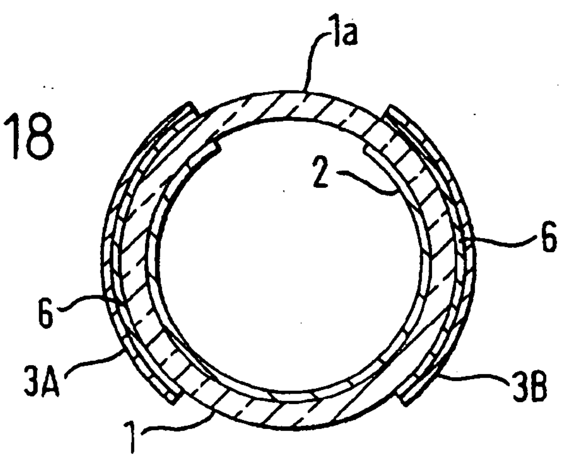


FIG. 17

FIG. 18



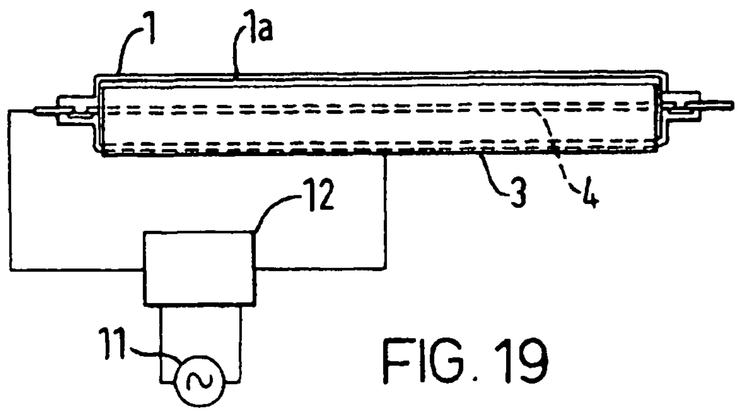


FIG. 19

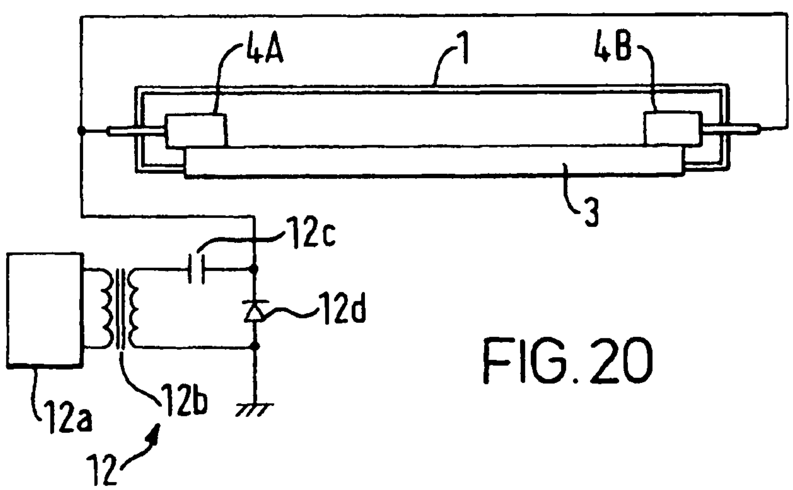


FIG. 20

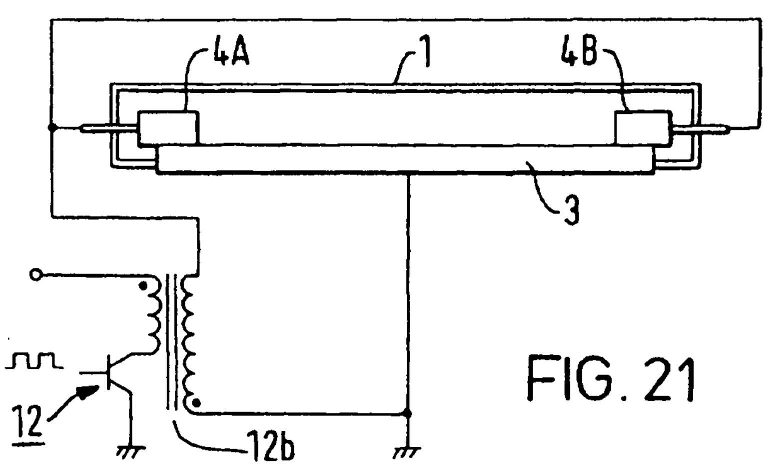


FIG. 21

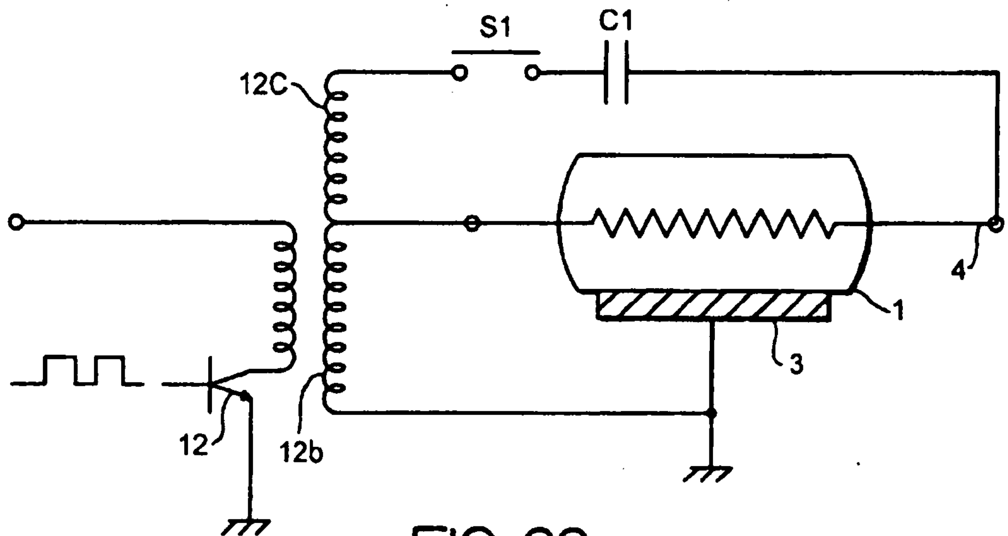

S1
C1
12C
4
1
3
12
12b

FIG. 22

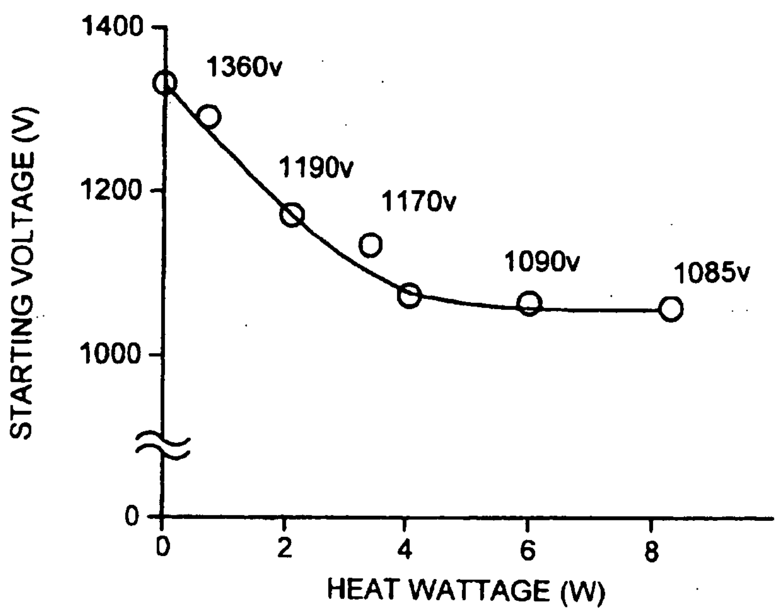

1400
1200
1000
0
1360v
1190v
1170v
1090v
1085v
STARTING VOLTAGE (V)
0
2
4
6
8
HEAT WATTAGE (W)

FIG. 23

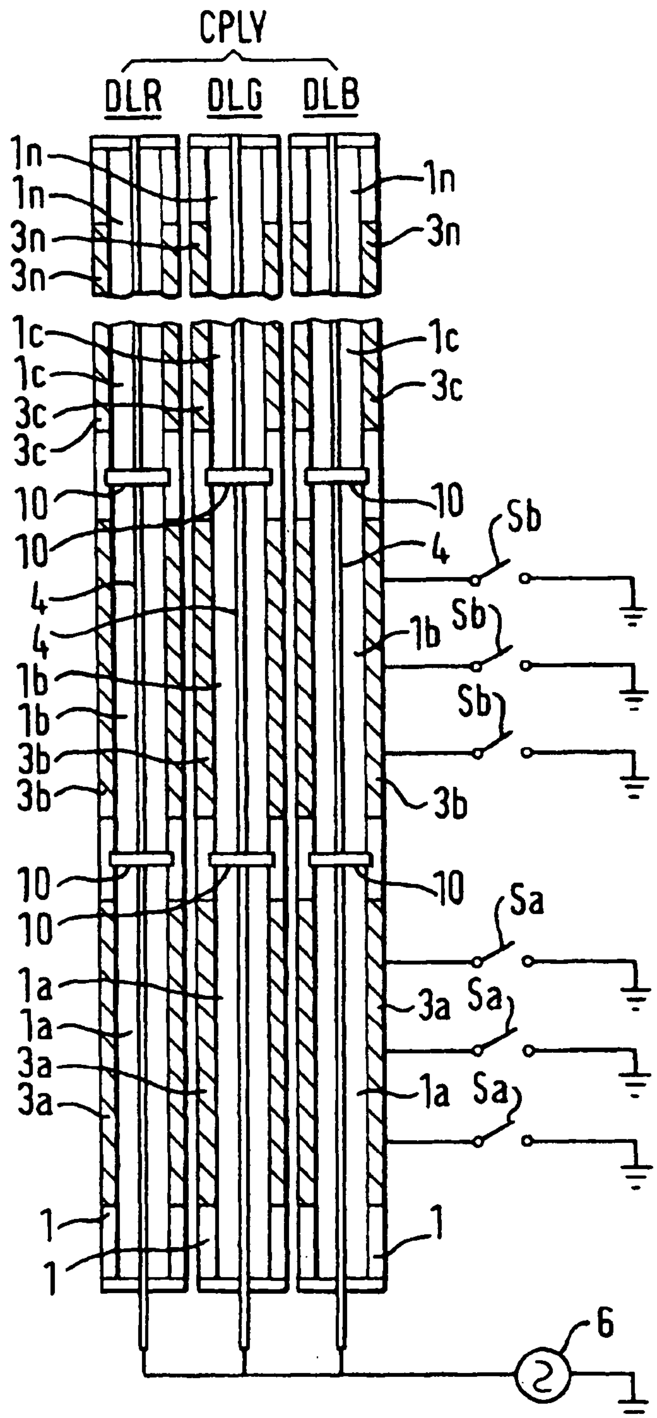

CPLY
DLR
DLG
DLB
1n
1n
3n
3n
1n
3n
1c
1c
3c
3c
1c
3c
10
10
10
4
4
4
Sb
Sb
Sb
1b
1b
1b
3b
3b
3b
10
10
10
Sa
Sa
Sa
1a
1a
1a
3a
3a
3a
1
1
1
6

FIG. 24

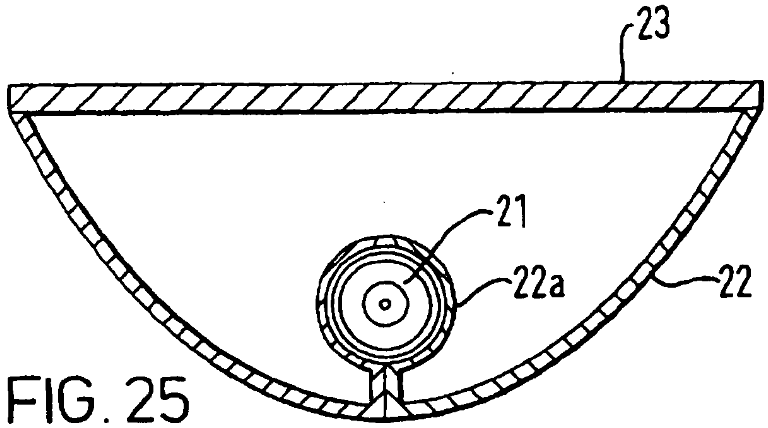


FIG. 25

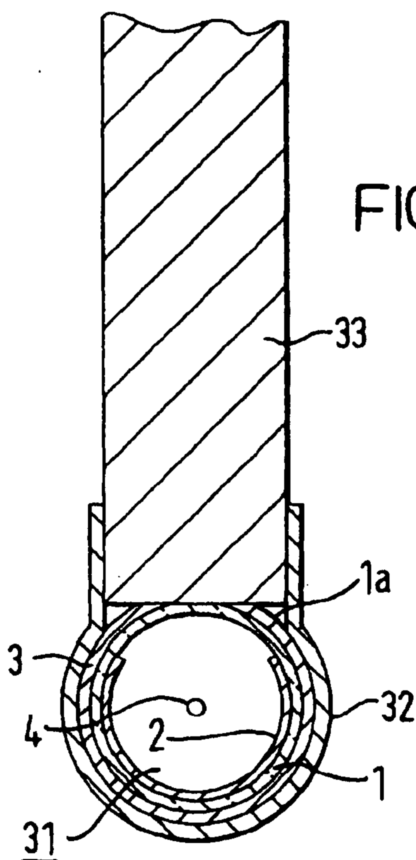


FIG. 26

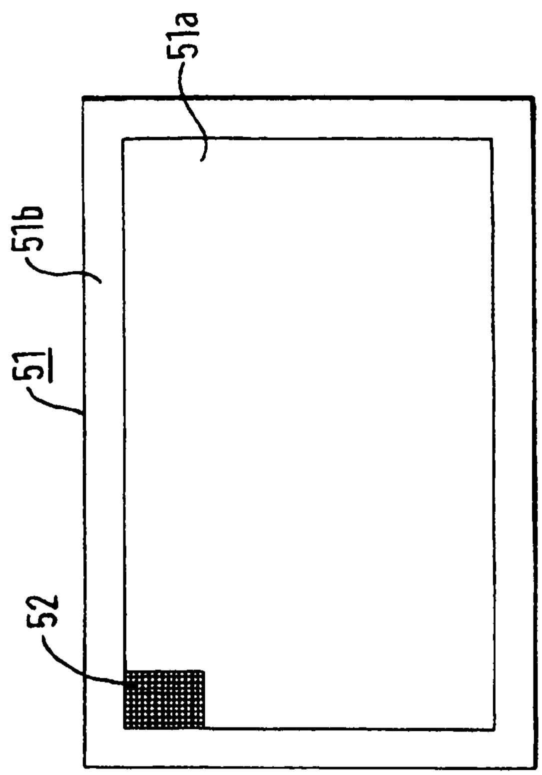


FIG. 28

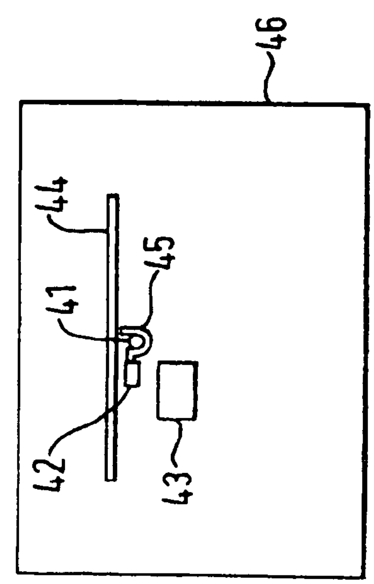


FIG. 27